MOBILE EXPERTS

EXPERT INSIGHT FOR RAN and In-Building Wireless Subscribers

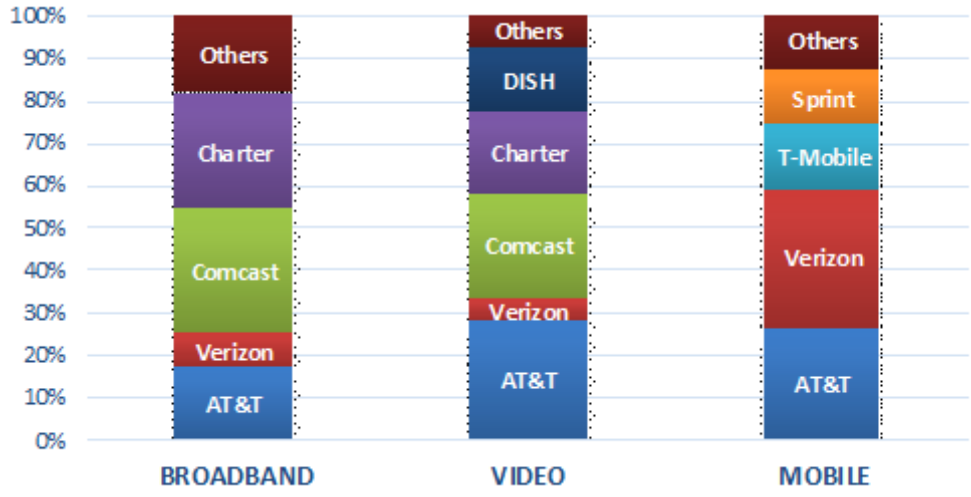
Cable Networks and Small Cells:

How Compatible Are They, and How Might They Be Used?

Background: Fixed-Mobile Convergence and Competition

While fixed and wireless operators continue to grow their respective businesses, the explosive growth of the past has become rare these days. Markets are reaching saturation points in developed markets such as the United States. Core video markets based on linear programming is seeing a loss of cable TV subscribers, as more people are opting for a growing list of over-the-top (OTT) video alternatives such as SlingTV, Netflix, Hulu, etc. According to MoffettNathanson, video subscriber growth declined at an annual rate of -1.3% even with OTT options factored in.[1] Thankfully for the cable operators, Internet data services continue to grow unabated. For the wireless operators, the picture is less sanguine. Unrelenting competition over the past few years has taken a toll as the market is saturated with promotions and "unlimited" plans with little prospect for ARPU growth in the near term. According to a Wall Street article citing the Labor Department's consumer price index, the cost of wireless service plans fell by about 13% during the past 12 months.[2]

As the players in traditional service "silos" look to attain scale through horizontal and vertical mergers, there is growing speculation that fixed and mobile operators may be eyeing each other's "greener pastures" for growth.



Note: Broadband and Video connections are based on household; Mobile connections are based on individual subscribers

Source: Mobile Experts

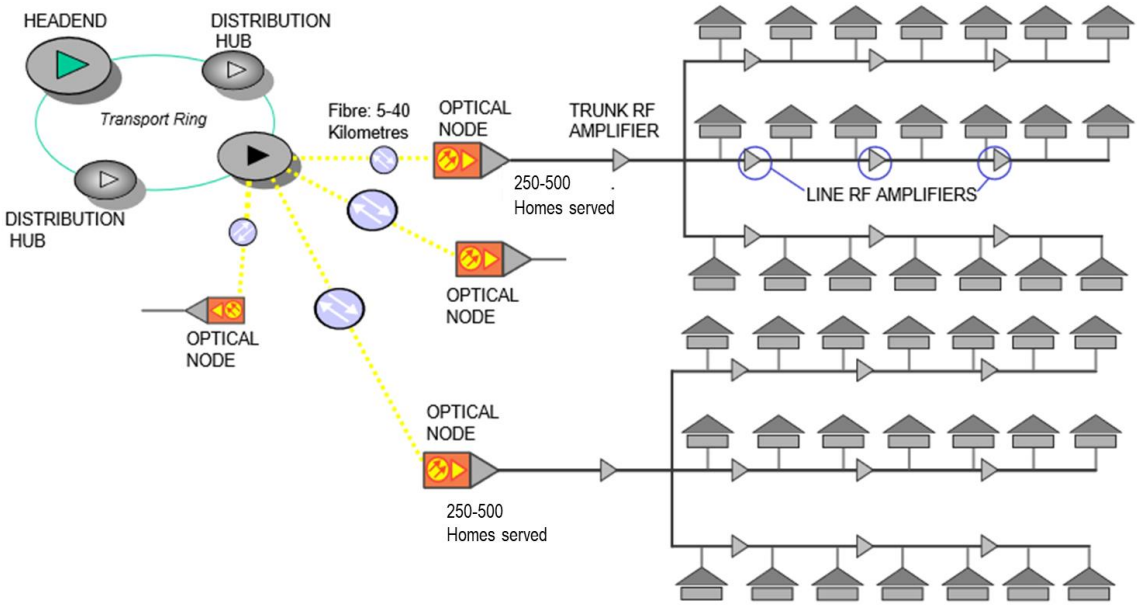
Figure 1: US Telecom Connections Share

[1] Multichannel.com, "Analyst: The Cord-Cutting Future has arrived," 3 May 2017.
[2] http://www.fiercewireless.com/wireless/cost-wireless-service-falls-13-biggest-decline-16-years-labor-dept

In context of myriad speculations around cable/wireless merger possibilities, there is a lot of interest in whether a cable network is suitable for wireless services based on LTE and upcoming 5G technologies. In this report, we explore the cable network infrastructure and shed some light on pending cable technologies that look to significantly expand speed and capacity, and whether such enhancements align well with pending 5G networks that mobile operators look to build. Moreover, the report highlights possible ways that cable operators may leverage their cable infrastructure along with small cell technologies to grow their prospect in mobile business.

Cable Network Overview – Fiber Deep and Capacity Expansion

Cable networks were originally constructed to carry TV signals terrestrially over a cable and has been re-purposed many times, and is now a dominant data network with broad coverage in the United States. Cable network is comprised of hybrid fiber coaxial (HFC) plant that carries RF signals from headend to individual homes. The distance from a headend or distribution hub to residential or business parks can be tens of kilometers. In length. For these "long" transmission links, fiber optic cables are used. Fiber nodes in neighborhoods and business parks then carry the signal to individual premises over coaxial cable. Since the transmission from a fiber node to individual homes can potentially be in thousands of feet, amplifiers are placed along a coaxial chain to re-generate the signal. (Note: "N+4" means that a coaxial chain has 4 amplifiers from a node to the last home in its chain.)

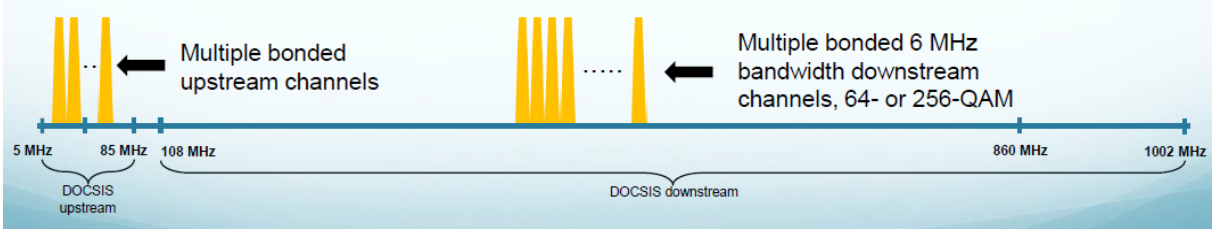


Source: Wikimedia Commons

Figure 2: Hybrid Fiber Coaxial Cable Plant

RF signals carry both video (i.e., pay TV cable channels) as well as DOCSIS data channels over a physical HFC plant. It should be noted that most cable networks serve about 250-500 homes per fiber node (i.e., *service group size*). The service group size generally comes down as operators take their fiber deeper into the network and split service groups to increase network capacity (i.e., analogous to sectorization and small cell densification in wireless). It should be noted that while old HFC plants typically have 6-8 fiber stands from Distribution Hubs to fiber nodes, hundreds of fiber strands are used for new optical fiber node builds and for network extension projects. Notably, the incremental capital costs to put in place a few fiber strands vs. hundreds of strands is de minimus.[3] For any new cable network builds, cable operators will likely deploy as many fiber strands as possible since the labor cost is the same whether a trenching is done for a single fiber vs. hundreds of fiber in a bundle.

At a high level, cable services are carried over RF signals, using frequency division multiplexing. The DOCSIS[4] data networking is managed by a headend equipment called Cable Modem Termination System (CMTS) which manages thousands of cable modems. The CMTS sends data using QAM modulation and down/up converted to RF using different frequency ranges for downstream and upstream links as shown below. Today's cable networks are typically provisioned for small upstream bandwidth around 42MHz. To support higher upstream capacity, some cable operators are contemplating moving this "split" to 85MHz or even higher at 200MHz.



Source: Dave Sinclair, SCTE "DOCSIS 3.1" presentation

Figure 3: Separate Frequency Bands for DOCSIS Downstream and Upstream

With the latest DOCSIS 3.1 technology transition, most cable operators are upgrading both HFC physical plants and network technology to increase network capacity in significant way.[5] Some of the major capacity expansion paths are outlined below:

[3] Edwin Mallette, "Brighthouse Networks, HFC and EPON over Coax", IEEE 802.3 EPOC Study Group, January 2012
[4] Data-over-Cable Service Interface Specification (DOCSIS) is CableLabs standard
[5] While most cable operators are upgrading to DOCSIS 3.1, some operators with favorable fiber footprint are going direct to FTTH such as Altice in old Cablevision footprint.

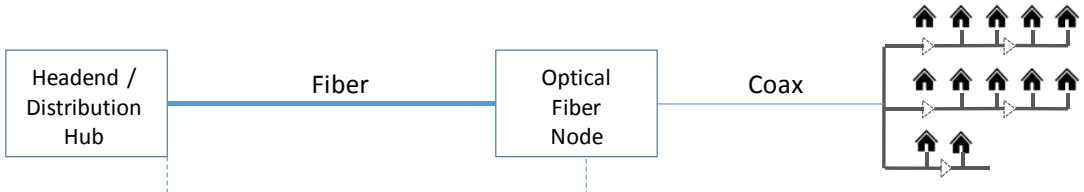
Table 1. Cable Network Capacity Expansion Options

Capacity Expansion Options	Network Benefits	Upgrades
Service Group Size Reduction	Effectively doubles service group capacity for each optical node split	HFC plant upgrade of additional optical fiber node including additional fiber pulled to a new fiber node; Headend upgrades on CMTS and Video Headend equipment
DOCSIS 3.1[6]	Higher spectral efficiency by leveraging OFDM, higher-order QAM, LDPC forward error correction, and multiple modulation profiles	Upgrade of CMTS and subscriber cable modems
HFC Spectrum Expansion	Extending operating frequency range from 800MHz to 1.2GHz provides additional channels for data/video services and higher up/down split to expand the upstream channels	HFC plant upgrades including optical fiber nodes, amplifiers, etc.
HFC Passive (N+0 Architecture)	Removing active amplifier components reduces non-linear distortion and noise and effectively raises optical/spectral efficiency. N+0 architecture lays the foundation for Coherent Optics and Full Duplex DOCSIS	HFC plant upgrades including removal of amplifiers and putting in place additional optical nodes
Next-gen PON Technologies	Next-generation PON technologies offer 10G+ capacity links over fiber	PON network overlay over fiber portion to node or all the way to homes

[6] For details on DOCSIS 3.1, please refer to CableLabs specifications

Coherent Optics	256 Gbps over 80 km over a single wavelength in lab test (26x increase over analog optical carrier between Headend and fiber node)[7]	Optoelectronic upgrades at Headend and optical fiber nodes
Full Duplex DOCSIS	10 Gbps symmetrical transport[8]	N+0 plant upgrade and CMTS and Cable modem upgrades

While the cable network capacity expansion options can be deployed separately to provide incremental benefits, it is likely that cable operators will employ a combination of technology options especially as they look to migrate to DOCSIS 3.1. The transition will also likely require a combination of HFC plant upgrades (for expanding both downstream/upstream split and spectrum expansion) and equipment upgrades to CMTS and cable modems. For example, a cable operator may look to *node plus zero amplifier* (N+0) architecture in conjunction with DOCSIS 3.1 transition with HFC plant upgrades for higher up/down split to offer higher capacity. The *service group* capacity can range from 1 - 10 Gbps in downstream and 100 Mbps – over 1 Gbps in upstream under various expansion scenarios.



N+4 Architecture (Today)

Plant	6-8 to hundreds of fiber strands	Coaxial distribution serving 400-500 homes per fiber node
Capacity	~10 Gbps per fiber (analog optic)	Service group capacity of ~1 Gbps down and ~100 Mbps up (DOCSIS 3.0)

N+0 Architecture (Future)

Plant	6-8 to hundreds of fiber strands	Coaxial distribution serving 25-40 homes per fiber node
Capacity	256 Gbps per fiber (via Coherent Optics)	Service group capacity of 5-10 Gbps down and 200 Mbps – 1+ Gbps up (DOCSIS 3.1)

Source: Mobile Experts

Figure 4: Fiber and Coaxial Plant Capacity Expansion in Cable Networks

[7] CableLabs blog: http://www.cablelabs.com/future-proofing-cables-optical-access-network-coherent-story/
[8] CableLabs blog: https://www.cablelabs.com/full-duplex-docsis/

With a combination of robust fiber plant extending deeper into its HFC plant and technology advancements to expand network capacity where fiber is constrained (digital coherent optics for example), a dense cable network with fiber nodes within 1000-1500 feet of residential and some business premises, may provide a good foundation for small cells.

Is Cable Network Capable of LTE and 5G Small Cell Backhaul?

Throughput capacity of about 100-150 Mbps downlink and 50-100 Mbps uplink, on a sustained basis, is required for a 20-MHz LTE-FDD small cell. Also, the delay latency between small cell and Evolved Packet Core (EPC) must be kept below 5 ms for optimal network performance. With cable operators moving to Distributed Access Architecture where physical layer of CMTS may be moved to a node deeper into the network, there is an opportunity to strategically deploy a higher up/down split--so that more channels and bandwidth can be provisioned for the upstream link. For example, with an up/down split at 200MHz, the DOCSIS 3.1 upstream service group capacity can extend to well over 1 Gbps. This amount of capacity can support tens of LTE small cells and may be sufficient to support a 5G small cell depending on how much 5G spectrum bandwidth is supported.

With a combination of HFC plant upgrade and DOCSIS 3.1, the DOCSIS/HFC plant can theoretically support LTE small cells, but the detailed feasibility depends on use case, traffic mix between traditional cable data and video services, and HFC/DOCSIS network configuration. The current cable network transition to distributed access architecture affords an opportunity to provision dedicated small cell backhaul services on HFC/DOCSIS plant and extending MPLS tagging for higher degree of QoS management away from shared cable data services.

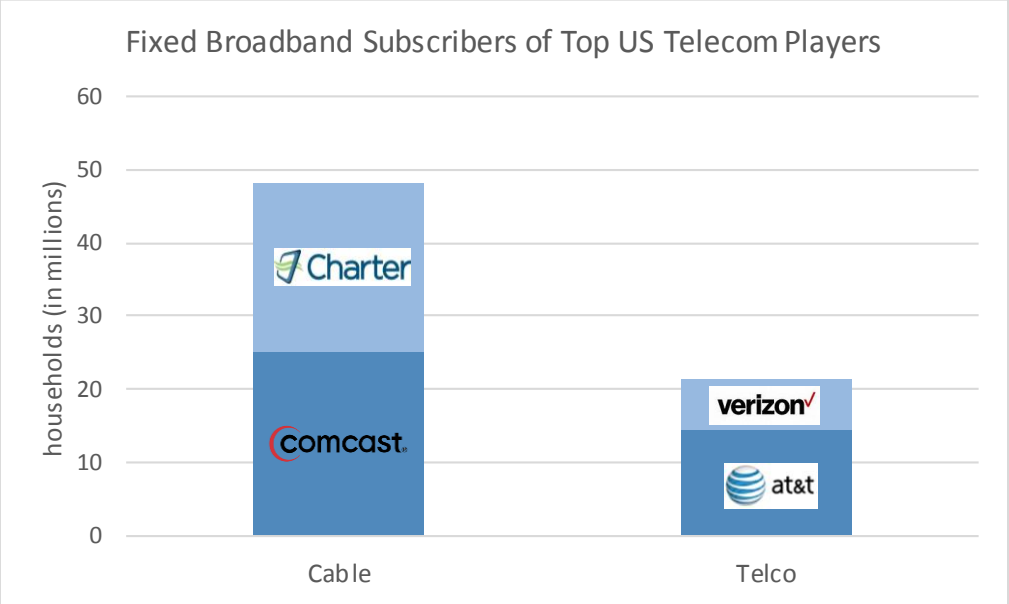
With the distributed access architecture transition, cable operators can continue to extend the fiber footprint, and increase the density of fiber strands, deeper into the cable networks. Increasing number of fiber nodes and the density of fibers pulled into those nodes offer a more straightforward path for fronthaul/backhaul connectivity option for small cells. Marrying next-generation PON technology along with getting rid of analog transmission over fiber to digital (i.e., coherent optics) likely results in capex and opex savings in the long run as well.

With the 5G standards still being finalized, it is hard to pin down the small cell backhaul/fronthaul requirements. With the potential for multiple 100-MHz channel bandwidth for 5G, it is reasonable to expect that the transport requirements for backhaul will certainly increase significantly. Overall, the cable network, especially the

increasing portion of fiber deep footprint, could offer density of fiber assets that will be critical in meeting this growing transport requirements for expanding licensed, unlicensed and shared spectrum bands available for small cells.

Cable vs. Telco Wireline Footprint

Cable networks have had distinct advantage over traditional copper-based DSL technologies in fixed broadband market. With a broad coverage and expanding wireline capacity through incremental headend and cable modem upgrades, cable operators have been gaining share from telco's broadband offerings based on DSL. As of early 2017, as shown below, the top two cable operators, Comcast and Charter, have a significantly greater share of fixed broadband subscribers than the top two telcos, AT&T and Verizon.

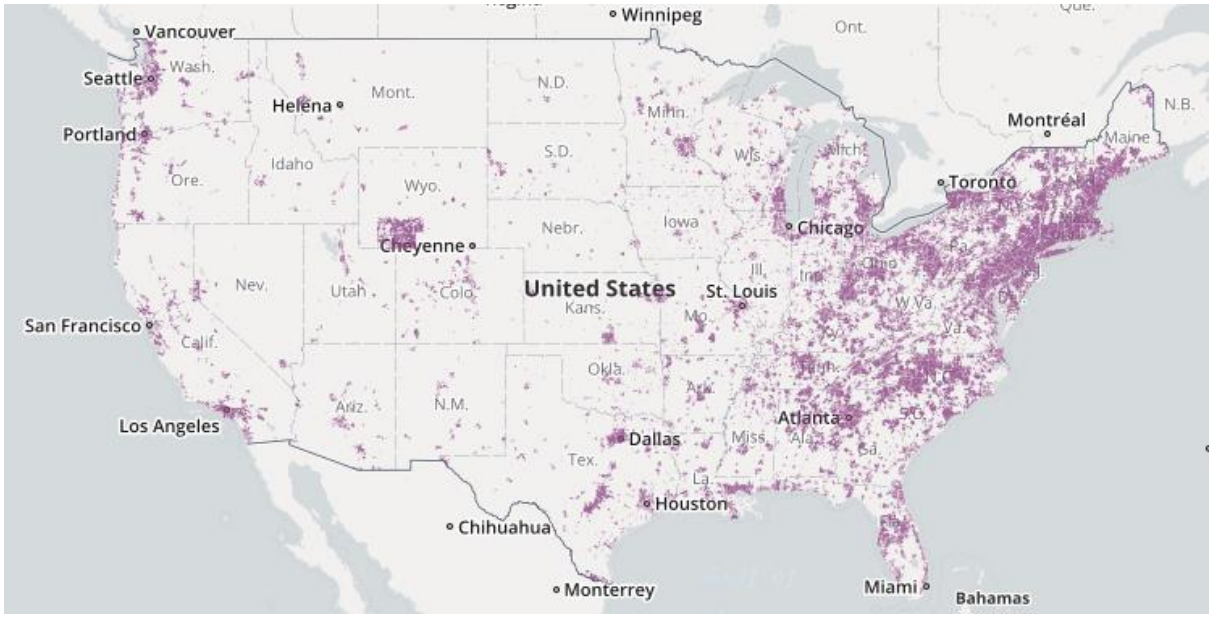


Note: as of end of 1Q 2017

Source: Mobile Experts

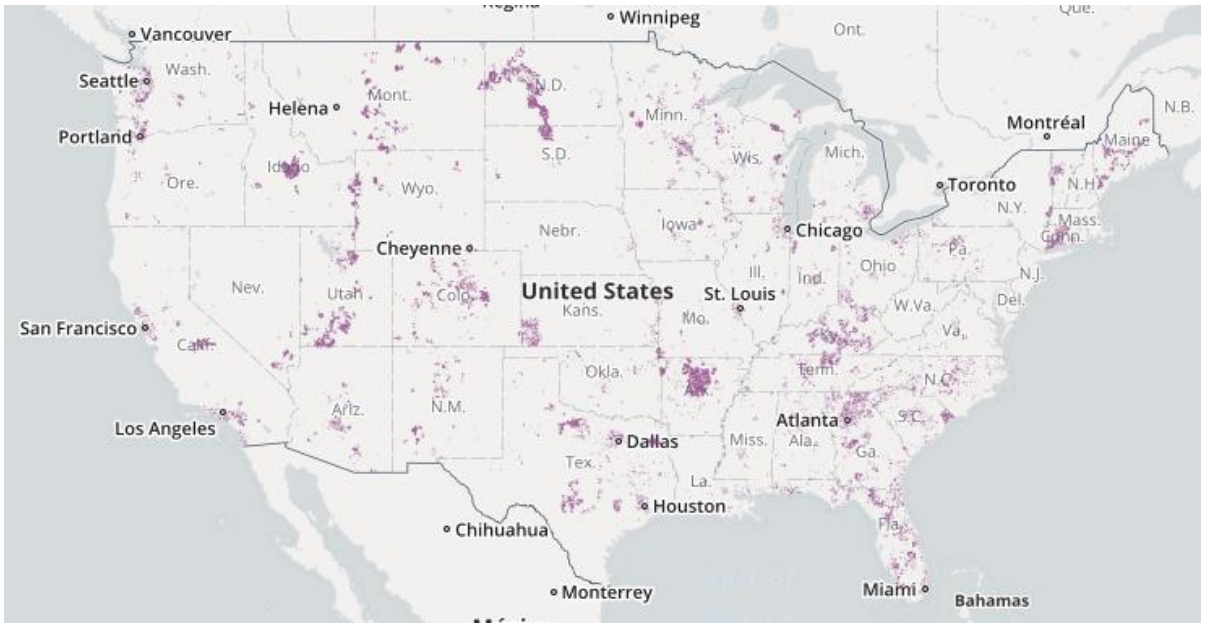
Figure 5: Cable vs. Telco Broadband Share

The price/performance advantage of cable's data service over telco's copper-based DSL broadband services is clear. The fixed broadband coverage maps of cable vs. DSL service footprints that meet the arbitrary FCC baseline of 25 Mbps (downlink)/3 Mbps (uplink) for high-speed fixed broadband service in the United States show a clear difference. The cable service footprint that meets the FCC fixed broadband service threshold is much more dense and broad than DSL-based service footprint today.



Source: FCC

Figure 6: Cable fixed broadband (25Mbps/3Mbps) coverage, as of June 2016

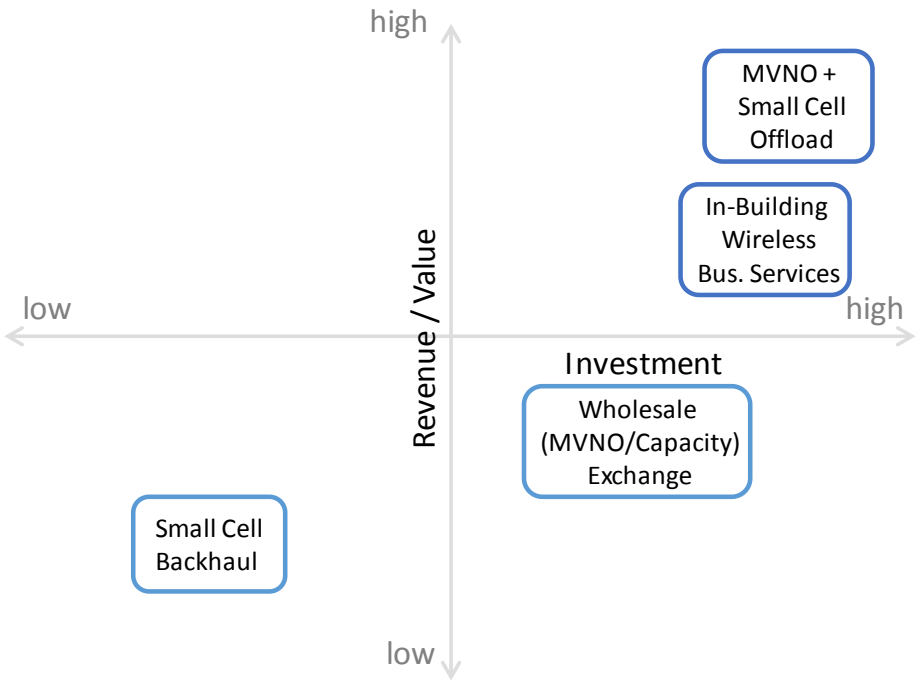


Source: FCC

Figure 7: DSL (incl. FTTN) fixed broadband (25Mbps/3Mbps) coverage, as of June 2016

Small Cell Opportunities for Cable Operators

Expanding network capacity of cable networks through DOCSIS 3.1 and "fiber deep"/DAA offers a unique opportunity for cable operators to leverage a growing ecosystem of unlicensed and shared spectrum small cell technologies including CBRS and MulteFire to enter wireless business in a 'capex-light' way. That is, cable operators can potentially leverage their cable network infrastructure for mobile backhaul – thus significantly lowering the overall cost per GB delivered wirelessly.



Source: Mobile Experts

Figure 8: Small Cell Opportunities for Cable Operators

There are several ways that cable operators can leverage small cell deployments on cable infrastructure to address opportunities in retail space:

1. *MVNO plus Small Cell network offload for retail mobile service* – cable operators can build owned CBRS or MulteFire small cell networks on top of cable infrastructure to offload LTE traffic onto owned network to minimize MVNO expenses;

2. *In-building wireless for enterprises* – cable operators can leverage CBRS or MulteFire small cells for indoor LTE service for enterprises.

Similarly, the small cell networks can be built to provide wholesale opportunities with mobile operators in following ways:

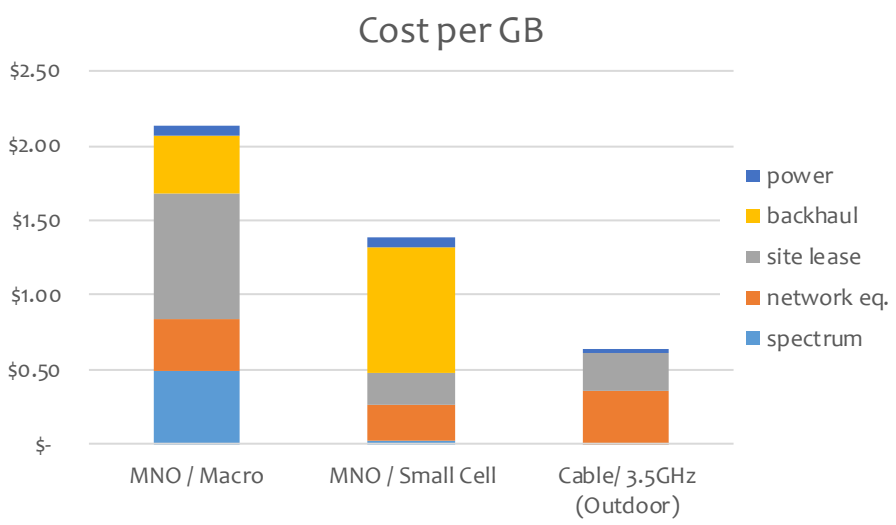
3. *Wholesale MVNO/small cell network capacity exchange or swap* – cable operators can build out small cells using CBRS and exchange that small cell (LTE) network capacity with mobile operators in exchange for favorable MVNO rates;

4. *Small cell backhaul or "Small cell as a service"* – cable operators can simply provide mobile backhaul service to mobile operators on its infrastructure or as an all-inclusive small cell as a service, including siting, power, backhaul and regulatory approval/buildout.

Small Cell Network plus MVNO for Retail Wireless

With intermodal competition starting to percolate in the United States with Comcast's MVNO launch this month and Verizon's foray into fixed wireless services using 28 GHz millimeter wave possibly later this year, competitive advantages for fixed and mobile operators may come down to who has the biggest "owner economics" in delivering data in fixed and mobile contexts. In other words, who can leverage owned network assets to keep the variable costs in check for the long run.

For cable operators leveraging MVNO, a profitability comes down to how much traffic can be offloaded to owned or cheaper networks. If more traffic is offloaded to cheaper or owned networks, the amount of traffic flowing to a mobile operator's network drops -- thus minimizing MVNO network expenses. The profitability of the MVNO business is directly tied to amount of traffic that can be offloaded. CBRS small cells can offer cheaper "cost per bit" economics than traditional licensed small cells. By leveraging cable network for backhaul and siting, the unit economics of cable-owned CBRS small cells can be significantly lower and offer profitable path for the MVNO business model.



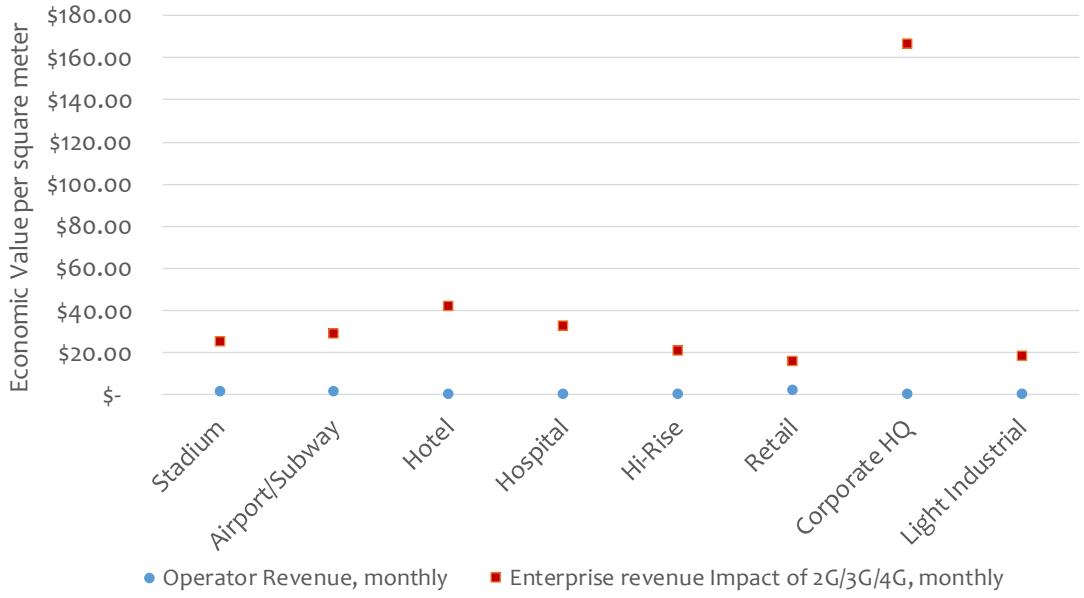
Source: Mobile Experts

Figure 9: Cost-per-GB Economics of Cable/CBRS vs. Mobile Operator Small Cell

With up to 150 MHz of spectrum available in the 3.5GHz CBRS band, cable operators can create formidable mobile wireless capacity--leveraging its underlying cable infrastructure for power, backhaul, and siting in some cases. Under the current CBRS rules, a cable operator can license up to 40 MHz of spectrum under a Priority Access License (PAL) and opportunistically leverage additional spectrum under General Authorized Access (GAA). With fiber nodes, on average, within 1000-1500 feet from homes and businesses, and extending closer (i.e., a few hundred feet) to those premises in fiber-deep N+0 architecture, CBRS small cells can likely provide decent coverage and capacity.

In-building Wireless for Business Services

Indoor mobile coverage is in high demand among key enterprises as consumers and workers alike increasingly rely upon their mobile devices for voice and data services. Enterprises have been frustrated by poor indoor mobile coverage for years. Although mobile operators have been investing tens of billions of dollars in capital expenditure each year, most of that capital expenditure is for macro network upgrades. The mobile operators' macro-first network investments have left indoor coverage issues to be resolved later, more or less, to be figured out by enterprises. The value of wireless is generally far higher for enterprises than for mobile operators.



Source: Mobile Experts

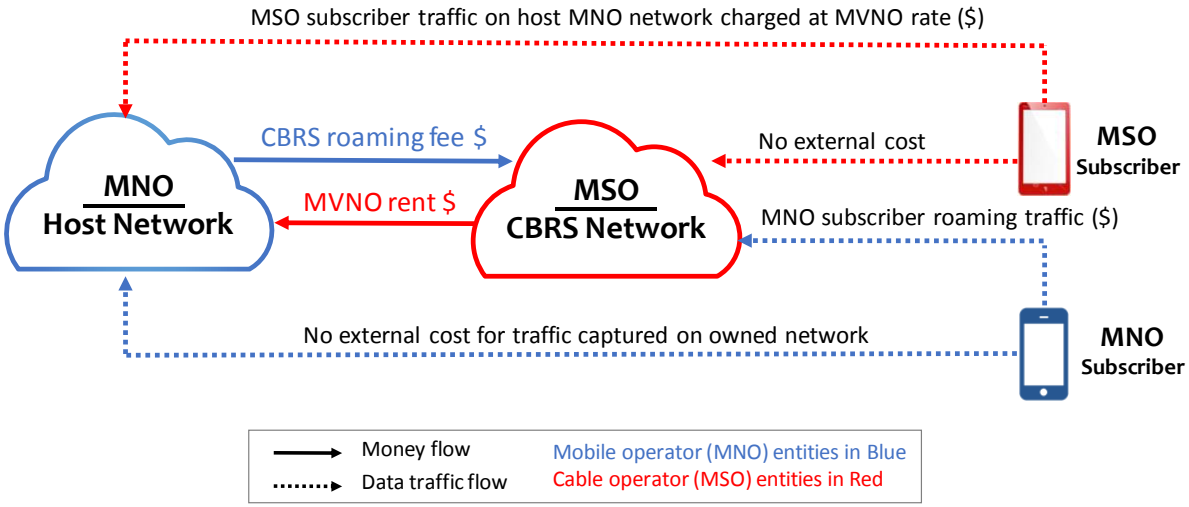
Figure 10: Value of Wireless across vertical industries

Not surprisingly, mobile operators are less inclined to invest in in-building wireless projects, while enterprises are more so. With shared spectrum technology like CBRS, the cable operators can potentially address this market demand by building out and managing CBRS small cell networks on behalf of key enterprise customers and provide back-end core network services with mobile operators to provide seamless mobile connectivity services. This business service can be an extension of its retail mobile business by leveraging existing EPC core network platform along with extensions of small cell networks strategically placed at key enterprise buildings along with strategic locations where consumers and workers spend most of their time.

Wholesale Exchange/Swap of Small Cell Capacity for Favorable MVNO Rates

Having owned small cell network where mobile traffic is consumed and generated – i.e., at homes and businesses – offer several advantages for cable operators. Besides leveraging the network for self-offload to minimize the MVNO "rent" costs, the cable operators can offer small cell LTE capacity at a wholesale rate to mobile operators in exchange for favorable MVNO rate or terms. As illustrated below, cable operator-owned (CBRS) small cell networks near homes and businesses would hopefully capture the bulk of mobile traffic. This would minimize cable subscriber mobile traffic going over to mobile operator's host network, and minimize the MVNO rent charge. Meanwhile, cable

operators can offer small cell network capacity to the host mobile operator at a wholesale rate to offset some of the MVNO rent charges.



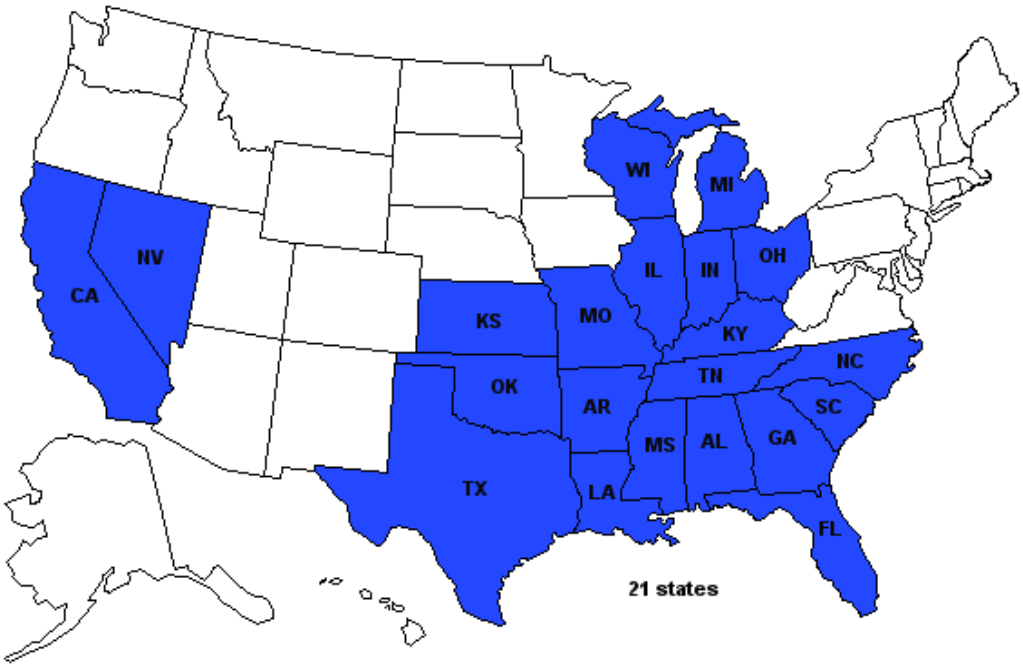
Source: Mobile Experts

Figure 11: MVNO/Small Cell Network Capacity Swap Business Model

The business terms or details can be complex as illustrated above, but it offers additional optionality for cable operators by having own small cell network.

Wholesale Small Cell Backhaul or Small Cell as a Service

Cable operators have been selling cellular backhaul services to mobile operators for some time, mostly for macro cell tower backhaul. As the pace of small cell network rollouts quickens, cable operators' dense network footprints are often mentioned as a good candidate for small cell backhaul. With limited wireline service footprints, even for integrated fixed/mobile players like AT&T and Verizon (see maps below), small cell backhaul, and other infrastructure elements such as siting, power, etc., will become important factors in expeditiously rolling out small cells.

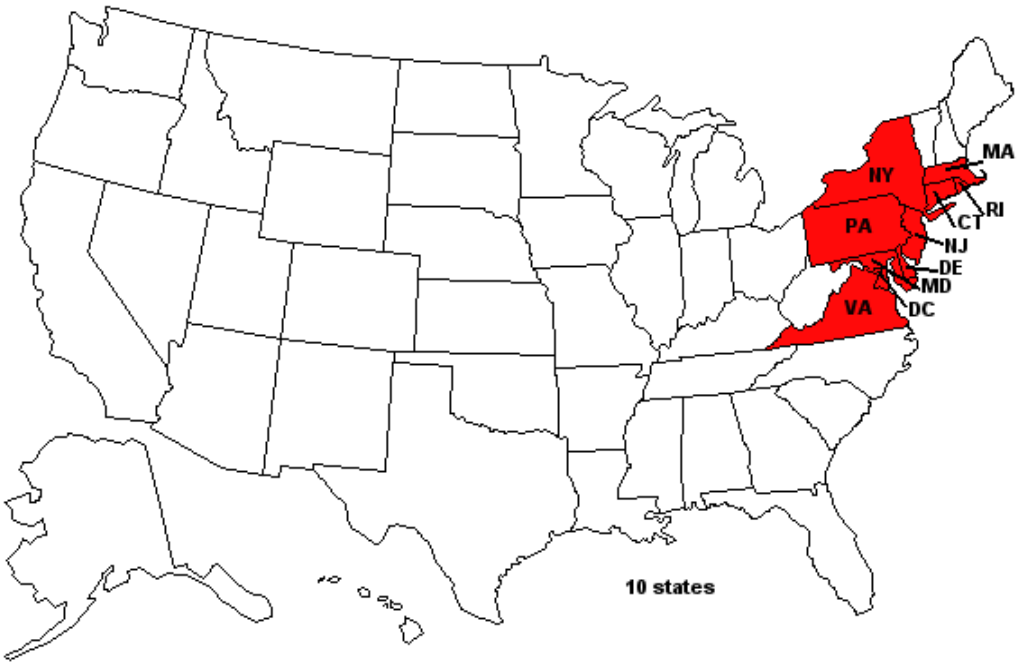


Source: Mobile Experts

Figure 12: AT&T Wireline Service Footprint

AT&T has been rolling out fiber-to-the-node (FTTN) infrastructure to support its U-verse high-speed data services and AT&T Fiber for deeper fiber penetration into its wireline footprint, so it may have sufficient fiber density in key metro markets to support its small cell rollouts. For broad deployments outside of its wireline footprint, it will require assistance of third-party infrastructure providers to deal with a complex web of infrastructure and regulatory issues that accompany such buildouts.

For Verizon, its wireline service footprint is now confined to just nine states and Washington, D.C. in the Northeast region, after sale of several key wireline operations in Texas, California, and Florida. The need for third-party partners for backhaul and other infrastructure services is even more acute for Verizon whose wireline footprint is limited.



Source: Mobile Experts

Figure 13: Verizon Wireline Service Footprint

While some cable operators welcome incremental business opportunities in cell backhaul services to mobile operators, some cable operators may view such opportunity with some skepticism – as the mobile operators compete with cable operators at the consumer level. Mobile telcos can potentially leverage cable infrastructure for backhaul to cannibalize fixed broadband services with fixed wireless substitutes. While selling "lit" fiber services for backhaul to mobile operators may be adequate, selling dark fibers to mobile operators may be viewed as strategically unfit especially in the context of fixed-mobile convergence competition. The fear for cable operators is that mobile operators can leverage fixed backhaul assets from cable operators to turn around and offer a fixed wireless broadband substitute. While this threat risk is minimal today, broad spectrum offerings combined with technology advancements such as millimeter wave broadband access can someday offer compelling wireless broadband alternative that can threaten today's cable broadband

superiority.

Cable operators can leverage infrastructure assets like fiber node cabinets, backhaul, and power, as a comprehensive infrastructure offering (i.e., small cells as a service) to mobile operators. For example, a "street furniture" asset like a hub cabinet (see above) offers a potential real estate asset upon which small cells can be mounted. Such offerings would be well received for mobile operators who face time-to-market challenges in capacity upgrades.

Summary

Cable networks are undergoing several technology and physical plant upgrades at the moment. Deploying DOCSIS 3.1 along with HFC plant upgrade for higher downstream and upstream spectrum bandwidths pave the way for 10Gbps downstream and 1 Gbps upstream capacity for a reduced service group of homes and businesses – further increasing per-home network capacity. Along with this technology transition, cable networks are moving towards a distributed access architecture, where certain cable data networking functions are distributed out to the edge, taking fiber deeper into the wireline footprint. Future technology like digital coherent optics can significantly increase the capacity throughput between cable headend/hubs to fiber nodes which will be within several hundred feet from homes and businesses when the coaxial portion of the HFC plant becomes all passive.

With the expanding cable network footprint on the horizon, cable operators are seriously contemplating several business opportunities in wireless possibly enabled through small cells on own cable network infrastructure. Less costly unlicensed and shared spectrum technologies like CBRS and MulteFire can potentially enable cable operators to create LTE network capacity that can be harnessed in multiple ways.

In retail, cable operators can leverage their small cell networks to capture traffic from their own mobile subscribers and leverage MVNO agreements for occasions when traffic is truly mobile or in places where owned small cells are not present. Moreover, cable operators can leverage CBRS small cells indoors in key enterprises to provide in-building LTE wireless services for key enterprises who are increasingly demanding seamless mobile coverage indoors.

In wholesale, cable operators can sell the small cell network capacity to mobile operators in exchange for favorable MVNO rates or terms or a remuneration of some kind. At a basic level, cable operators can also leverage its cable infrastructure and sell a small cell

backhaul service or a "small cell as a service" bundle including backhaul, siting, power, and even possibly construction. There are strategic implications of these options, and it is likely that large cable operators who have an aspiration of entering the mobile wireless business may look to harness the cable network infrastructure for own use rather than offering wholesale services to mobile operators.

Cable operators still need to make further investments in network infrastructure, including the HFC plant upgrade towards the N+0 architecture, DOCSIS 3.1, network partitioning for different residential and business services, other technology upgrades to fully realize the multi-Gbps wireline network infrastructure, and additional power infrastructure to support additional fiber nodes and small cell radios. Unlicensed and shared spectrum technology options like CBRS and MulteFire afford a good opportunity for cable operators to make a serious dent in the mobile wireless ecosystem. It will take some time for the network and operational capabilities to mature, but sign posts are pointing towards that future.

Overall, the technology and plant upgrades that are underway in the cable world provide a suitable pathway for 4G and 5G backhaul. The challenges of leveraging cable infrastructure for mobile services are strategic. The wholesale opportunity of leasing cable network to mobile operators is challenged by strategic concerns of mobile-fixed competition at the retail level. However, an opportunity to leverage network assets for own wireless play provides a more appealing prospect for cable operators. Mergers may eventually break this logjam, setting up a round of small cell and 5G deployment that heavily leverages cable assets.